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Energy-saving potential of the industrial sector of Taiwan

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ABSTRACT

The purpose of this article is to assess the maximal reduction potentials of energy use and greenhouse gas (GHG) emissions for the six most energy-intensive industries in Taiwan-chemical materials, electric machinery, iron and steel, textiles, cement, and paper and pulp. The assessment methodology is based on the so-called Best Available Technologies (BAT) by the Internal Energy Agency (IEA). By taking 2010 as base year, the assessments resulted that the total energy savings in Taiwan's industrial sector will be 66.3 TWh, about 5.3% of the national energy use per year. Wherein, the heat saving is 49.7 TWh, the electricity saving is about 16.6 TWh. The maximal GHG emissions reduction of these six industries reaches 16.2 Mt-CO_{2e}, about 6.4% of the national GHG emissions. The energy use and GHG emissions in the industrial sector account for about 53.8% and 48.3% by taking the entire nation as a whole. Meanwhile, the industrial annual production value in Taiwan is up to NT$ 14.7 trillion. Therefore, if the energy use and the GHG emissions were improved as the above assessments, the country's overall economic strength and environmental integrity will be enhanced substantially and significantly.

Contents

1. Introduction

Industrial sector–the largest final energy use sector in Taiwan–accounted for 53.8% of the total energy use [1], emitting 48.3% of total carbon dioxide [2]. Hence, we can say that the energy use and carbon dioxide emissions have a direct positive correlation. In other words, energy saving means emissions abatement. According to the statistics of Directorate-General of Budget, Accounting and Statistics, Executive Yuan [3] and Bureau of Energy, Ministry of Economic Affairs (MOEABOE) in 2010 [1], the gross production and energy use of the manufacturing sector respectively accounted for 26.03% and 53.81% of the nation's, which were disproportionately compared to the services sector's

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(i.e., 67.24% and 10.95%). Therefore, to achieve low energy intensity and high production efficiency to thereby improve national economic competitiveness, the first step has to start from the industrial energy saving.

The purpose of this article is to assess the energy-saving and emissions-reducing potentials, under the BAT (Best Available Technologies) scenario, for the industrial sector of Taiwan. The six most energy-intensive industries in Taiwan, in the order from large to small, are chemical material, electrical machinery, steel and iron, textiles, cement, paper and pulp [4]. According to the statistics by Ministry of Economic Affairs (MOEA) in 2010, the above six industries used 83.4% of the total final energy used in industrial sector [4], accounting for 44.92% of the nation's [1]. Meanwhile, the output value of these six industries accounted for 81.37% of the entire industrial sector's [5]. Therefore, assessing the energy-saving and emissions-reducing potentials of the above six industries, if they were implemented with the energy-saving technologies such as BAT, should be sufficient as a representative of the energy-saving and emissions-reducing potentials of the entire industrial sector. Because the industrial annual output value is as high as NT$ 14.7 trillion, equivalent to the national economic share of 44.7% [5], if the energy use and carbon emissions of the industrial sector are really reduced, the overall economic strength and environmental protection can be benefited for our country in a substantial and significant scale.

According to the BP statistics for 2006, the primary energy resources used in the world were about 470 EJ/yr, while the total energy use in the industrial sector was approximately 120 EJ/yr, which accounted for about one-third of the global final energy use, and one-fourth of which was electric consumption [6]. Meanwhile, the industrial sector emitted 40% of the global energy-related GHG [6]. If the global industrial sector practiced BAT, the energy-saving potential might be up to an average of 18%, while the emissions-reducing potential would be between 12% and 23% [6]. Among the industries, the cement industry has the greatest potential for both the energy saving and emissions abatement.

2. Literature review

The industrial sector almost always has been the most energy-intensive sector in all the countries. For example, the energy use of Chinese industrial sector accounted for as much as 70% [7]. In 2007, the industrial sector used 127 EJ of energy (i.e., 1/3 of the global energy use) [8]. Whereas, the industrial sector of OECD (Organization for Economic Cooperation and Development) countries used 51 EJ, accounting for 40% of the global industrial energy use. In terms of individual industry, the most energy-intensive industry is the petrochemical. Indeed, the industrial sector is one of the primary targets during the energy-saving potential investigation. For decades, the relative studies have never been stopped.

In 1978, on the base of energy availability and end-use conditions, Lewis [9] applied the classification model (i.e., the disaggregated model) to find that there was about 30% of energy-saving potential in the UK's industrial sector. Wherein, the energy-saving potentials for its industries are 35% for the food and beverage and the building materials, followed by 33% for the engineering and metal trade, the steel (30%), the textiles and leather (29%), the chemical and related trade (24%), the paper, printing and stationery (22%), and other industries (30%). In terms of energy-saving form, there were about 26% saving of electricity, 55% saving of natural gas, and 63% saving of oil product, but there would be 30% increase of solid fuel use.

In 2003, Kablan [10] focused his insights on the energy problem in Jordan and specifically on the energy-saving status in the industrial sector. Same as Taiwan, Jordan is a non-oil-producing country and imports oil from neighboring countries to meet about 94% of its energy needs. Except discussing the energy-saving status of Jordan's industrial sector, that study also put forward some measures to solve the relative energy conservation problems.

In 2003, the industrial output of Maharashtra accounted for 15% of the Indian industrial production. Wherein, the power consumption accounted for 37.58% of the total electricity consumption in the region [11], the energy development agencies estimated that there were nearly 30,000 plants totally having an energy-saving potential of 25% [12]. In Maharashtra, the paper-making and textiles industries had the highest energy-saving potentials (about 20–25%), followed by the ceramics and glass (about 15–20%), the cement (10–15%), the fertilizer (10–15%), the steel (8–10%), the aluminum (8–10%), and the oil refinery (8–10%) [11].

In 2006, the Indonesian energy and mineral resources center had developed the energy conservation goals. According to their estimates, the energy-saving potential in the industrial sector of Indonesia was about 15–30% [13]. To achieve this goal, the Indonesian government scheduled to take the implementation of energy audit, energy labels and other measures, such as ESCO (Energy Service Companies).

In 2007, Djemaa [14] applied Markal model with 15 kinds of commercial energy-saving technologies to analyze the long-term energy saving potential of the French industries, like, steel, paper and pulp. The results showed that, in 2030, the power of the pulp production industry will be reduced up to 25%, but at the same time, the thermal energy use will increase 5%; the heat use of the paper industry will be reduced by 31%; and the use of electricity will increase by 23%. The electric and thermal energies of the steel industry can be reduced by 10% and 20% respectively [14].

In 2007, the IEA applied the best commercialized technology to assess the global industrial energy-saving potential. In their estimation, the largest energy savings was from the cement industry (28–33%), followed by the paper industry (15–18%), the petrochemical industry (13–16%), the steel (9–18%), and the aluminum (6–8%). As far as the petrochemical industry, the energy-saving potential of the U.S. was up to 29.8%, followed by China (20.5%), Japan (10%), and Germany (9.8%) [15].

In 2010, in accordance with the energy audit, the adjustment and replacement of boilers and the combinational analyses of motor and steam systems, Pakistan's Ministry of the Environment estimated that its industrial sector had the energy-saving potential of about 15–25% [16], equivalent to about 43 percent of the national energy use per year.

In 2010, United Nations Industrial Development Organization (UNIDO) assessed the short-term global industrial energy-saving potential, finding that there was about 15% of the energy-saving potential (7.6 EJ/yr) for the industrial sector of the industrialized or high-income countries (or industried countries, ICs) [8]. In terms of individual industry, the alumina had the largest energy-saving potential (35%), followed by the glass, ceramics and lime (30–35%), the pulp and paper (25%), the food and beverage (25%), the steam cracking and petrochemical excluding raw materials (20–25%), the cement (20%), the oil refining (10–25%), the refined zinc alloy (16%), the ammonia (11%), the textiles (10%), the steel (10%), and the methanol (9%) [8]. Moreover, the non-ICs had the greater energy saving potential (about 30–35% or 23.4 EJ/yr) than those of the ICs countries overall. In terms of individual industry, the alumina production had the greatest energy saving potential of 50%, followed by the copper smelting furnace (45–50%), the refined zinc alloy (46%), the oil refining (40–45%), the glass, ceramics and lime (40%), the food and beverage (40%), the steel (30%), the steam cracker excluding raw materials (25–30%), the cement (25%), the ammonia (25%), the pulp and paper (20%), and the textiles (20%) [8].

In 2010, Li et al. [17] introduced the energy use status to the China's key energy-intensive industries. Additionally, the main technical bottlenecks and resource-environmental problems were analyzed with special emphasis on energy utilization efficiency, energy use mode and waste emissions. At policy level, Chinese government combined the national circular economy structure with the energy conservation policies and programs as the macro-measures to solve these problems.

In 2010, Chan et al. [18] performed on-site energy audits for 118 firms in Taiwanese iron and steel industry. The results showed that the total energy-saving potential was about 79,200 kilo-litters of crude oil equivalent (kloe), equivalent to a carbon dioxide emissions reduction of 217,800 t.

In 2011, Rocky Mountain Institute assessed the energy-saving situation in the United States, on the base of energy-efficient technologies, for example, cogeneration and waste heat recovery power generation. According to their assessments, the industrial sector of the United States can reduce energy use about 47 trillion BTU per year till 2050, representing an energy-saving potential of 27–30% [19]. In the same year, the Lawrence Berkeley National Laboratory assessed the energy-saving potential for the Chinese industrial sector, which was up to 31–54% till 2050, on the base year of 2005, if China could accelerate the improvement of energy efficiency, wherein the steel industry had the largest energy-saving potential of 54%, followed by ammonia (53%), aluminum (42%), cement (38%), papermaking (38%), flat glass (37%), and ethylene (31%) [20].

In 2012, Fleiter et al. [21] assessed 17 process technologies to improve energy efficiency in the German pulp and paper industry by using a techno-economic approach. Those technologies resulted in energy saving potentials of 34 TJ/yr for fuels and 12 TJ/yr for electricity till 2035, which respectively equaled 21% and 16% of the total fuel and electricity demands. The energy savings can be translated into the mitigated CO_2 emissions of 3 Mt. The large part of the energy-saving potential is economically viable. Meanwhile, the most influential technologies are heat recovery and innovative drying in paper mills.

In 2012, Aranda-Usón et al. [22] provided energy use status for the four Spanish industries, by means of in-situ energy audits and complementary data. The results showed the estimation of energy use in each industry: food, drink and tobacco (9.6%), textiles (4.5%), chemical (14.7%), and non-metallic mineral products (24.3%), as well as the degree of inefficiency of each. The data were obtained by means of a stochastic frontier production function model. The results were combined with the energy use analysis to identify an energy-saving potential or opportunities of around 20.0% of the total energy use for all the studied industries.

In terms of industrial facilities or devices, the European Union (EU) had assessed the energy-saving potentials for the industrial sectors in the EU-27. According to their estimates, the compressors, pumps and fans had the greatest energy-saving potential of about 40%, followed by cooling (30%), lighting (32%), and motor (38%) [23]. The fields of assessments included steel, paper, printing, chemicals, nonmetallic minerals, food, beverages, tobacco, etc.

In fact, there are a great deal of energy-saving potentials in the industrial sector of Taiwan as well. Therefore, when vigorously promoting carbon-reducing measures, Taiwanese government should also take the promotion of industrial energy efficiency as the reference of energy-saving measures.

3. Taiwan's industrial structure and energy use

Table 1 shows the details of the energy use of Taiwan's six largest industries in 2010. The petrochemical industry had the highest energy use (65%). No doubt, oil product was the most used energy resources. By contrast, in the electrical machinery (second-ranked industry), electricity was the most used energy resources (94%). In the steel and textile industries, electricity was also ranked first in the category of energy use. As for the cement industry, the primary energy use was coal. Overall, the main energy resources consumed in Taiwanese industrial sector were electricity (34.9%) and oil products (35.9%). By contrast, the energy use percentages of coal and natural gas were lower in the industrial sector, because these two kinds of energy resources were mostly used in power generation plants. Therefore, the coal-fired and gas-fired power generations accounted for as high as 74.5% of the total power generation in this country [1].

In Table 1, from the references [2,4], the energy uses and GHG emissions of the six most energy-intensive industries are listed. To analyze more specifically, the energy use (10^3 kloe) and GHG emissions (Mt-CO_{2e}) for each industry are respectively divided by the output value [5], as shown in Table 2. Thus, we can get all the industrial energy intensities (liters oil equivalent (loe)/thousand NT$) and emissions intensities (kg-CO_{2e}/thousand NT$).

Please refer to Table 2. By comparing the quantities of energy use per output value-energy intensity (loe/thousand NT$), we can judge which industry belongs to the group of high energy-intensive industries in Taiwan. In the six industries, the energy intensity of cement (50.51 loe/thousand NT$) is the highest, followed by petrochemical (16.16 loe/thousand NT$), both of which are significantly higher than the national average—8.45 loe/thousand NT$. The super lower ones are electric machinery (1.18 loe/thousand NT$), steel and iron (4.26 loe/thousand NT$) and textiles (4.57 loe/thousand NT$).

On the other hand, the industries with emissions intensities far over average (10.03 kg CO_{2e}/thousand NT$) are cement (143.65 kg

Table 1
Energy use structure and GHG emissions in the six largest industries of Taiwan (2010).

	Energy use structure (10^3 kloe) [4]					GHG emissions [2]	
	Electricity	Coal	Oil products	Natural gas	Subtotal	Mt-CO_{2e}	Sectoral share (%)
Chemical materials	7,080.4	4,271.0	21,814.4	284.7	33,450.9	86.4	70.3
Electric machinery	8,976.4	–	119.3	88.2	9,184.0	10.5	8.5
Steel and iron	3,674.2	1,673.2	466.5	232.4	6,046.4	11.8	9.6
Textiles	1,537.2	76.8	564.2	26.4	2,204.7	3.7	3.0
Cement	483.5	1,238.8	106.2	–	1,828.4	5.2	4.2
Paper and pulp	836.8	319.7	167.4	5.9	1,329.7	2.5	2.0
Total	22,588.5	7,579.5	23,238.0	637.6	54,043.6	120.1	97.7
Sectoral share (%)	34.9	11.7	35.9	1.0	83.5	97.7	97.7
Industrial sector	30,908.7	7,890.5	24,810.0	1,126.6	64,735.9	122.9	100

Note: 10^3 kloe = 10.46 GWh.

Table 2
The energy use and GHG emissions of the six largest industries in Taiwan—petrochemical, electrical machinery, iron and steel, textiles, cement, paper and pulp (2010).

Index	Energy use [4]	Industrial sector share	Yield[a]	Output value [5]	Specific product energy use[b]	Energy intensity[c]	Specific product GHG emissions[d]	Emissions intensity[e]	Main product	Main energy use process
Industry/unit	10^3 kloe	%	Mt	100 million NT$	loe/kg	loe/10^3 NT$	kg CO_{2e}/kg	kg CO_{2e}/10^3 NT$		
Petrochemical	33,450.9	51.67	4.2	20,700	0.65	**16.16**	**5.20**	**41.74**	Ethylene	Distillation
Electric machinery	9,184.0	14.19	–	78,000	–	1.18	–	1.35	Semi-conductor	Clean room HVAC
Iron and steel	6,046.4	9.34	15.81	14,187	0.38	4.26	0.75	8.32	Crude steel	Iron oxide reduction in blast furnace
Textiles	2,204.7	3.41	3.88	4,820	0.57	4.57	0.96	7.68	Chemical fiber	Fiber-making, spinning, dyeing and finishing
Cement	1,828.4	2.82	16.88	362	0.11	**50.51**	0.31	**143.65**	Cement	Clinker calcinations, grinding
Paper and pulp	1,329.7	2.05	4.45	1,679	0.30	7.92	0.56	14.89	Paper	Pulping, papermaking
Total or average	54,043.6	83.48	–	119,748	–	4.5	–	10.03	–	–

[a] Steel News Letter, Customs Import and Export Statistics, Metal Center, and Taiwanese Paper Industry Association
[b] Specific product energy use = Energy use ÷ Yield.
[c] Energy intensity = Energy use ÷ Output value.
[d] Specific product GHG emissions = GHG emissions (in Table 1) ÷ Yield.
[e] Emissions intensity = GHG emissions (in Table 1) ÷ Output value.

CO_{2e}/thousand NT$) and petrochemical (41.74 kg CO_{2e}/thousand NT$), while the industry with super lower emissions intensity is still the electrical machinery industry (1.35 kg CO_{2e}/thousand NT$). Obviously, the industry having higher emissions intensity will also have higher energy intensity, vice versa.

Additionally, in Table 2, we also calculated the "specific product energy use" (loe/kg) and "specific product GHG emissions" (kg-CO_{2e}/kg) of the main product of each industry. By comparing these two values with the IEA's benchmarks, for example, the BAT or BPT (Best Practice Technology), the corresponding energy-saving and emissions-reducing potentials can be calculated.

4. Introduction to industrial processes and the latest energy-saving technologies

There are two kinds of energies generally used in the industrial processes, namely, heat and electricity. In terms of manufacturing facilities, the former is mainly demanded by boilers, while the latter is mostly used by motors. The common energy-saving measures for boilers are high efficient combustion techniques and excellent performance heat transferring mechanisms, while those for motors are inverters and power control techniques.

4.1. Introduction to petrochemical processes and their latest energy-saving technologies

After fractionation and refinery, crude oil can produce LPG, gasoline, naphtha, kerosene, diesel oil, fuel oil, lubricating oil, tar and other products. Furthermore, after cracking reaction, the naphtha can be changed into ethylene, propylene, butadiene (e.g., the main products of China Petroleum Company and Formosa Plastics in Taiwan). In the above processes, the temperatures rise approximately 815–870 °C, while the exerted pressures are about 15–20 atm. The most used energy is heat.

Ethylene, the main intermediate product of petrochemical industry, may be cracked from natural gas, crude oil, naphtha or ethane. In the global petrochemical sector, the share of ethylene produced from naphtha is 45%, followed by 35% from ethane, 12% from LPG and 5% from gas-oil. Energy demand is significant diverse if different raw materials are used to produce ethylene. For example, 15–25 GJ of energy is needed in producing one ton of ethylene from ethane, about 25–40 GJ/ton-ethylene from naphtha, while the most energy intensive one 40–50 GJ/ton-ethylene is from gas-oil [24].

The energy-saving share of each kind of BPT in the global petrochemical industry is described in Fig. 1.

4.2. Introduction to iron and steel production and its latest energy-saving technologies

There are three main procedures in the iron-and-steel making process: iron making, steelmaking and rolling. Their energy use shares are 70.6%, 2.9% and 14% separately. In the traditional steelmaking industry, most of the energy-intensive processes come from the equipment of blast furnace. Basically, the common smelting facilities used in Taiwanese steel and iron industry are blast furnace and electric arc furnace; the former is mainly for iron making, while the latter is mostly for steelmaking. Proposed by Asia-Pacific Partnership on Clean Development and Climate (APP), the appropriate energy intensity of steelmaking is between 20 and 35 GJ/ton-crude steel [26].

In view of the existing inherent limitations, various innovative energy-saving technologies in the iron-and-steel making industry are emerging. The most important technology is natural gas-based DRI (Direct Reduced Iron) currently used for the replacement of blast furnaces. In addition, there is Smelt Reduction that uses steam coal instead of coke in the iron making. Smelt Reduction now has evolved from demonstrative phase to commercial phase and will be a major trend in the future. Other common energy-saving measures are the reuse of scrap steel and the power generation of furnace gas.

The shares of energy-saving potentials of global iron & steel industry under BAT scenario are shown in Fig. 2.

4.3. Introduction to textiles manufacturing and its latest energy-saving technologies

General textiles manufacturing process can be categorized into four sub-processes: fiber manufacture, spinning, weaving and dyeing or printing. In the textile industry, the thermal energy

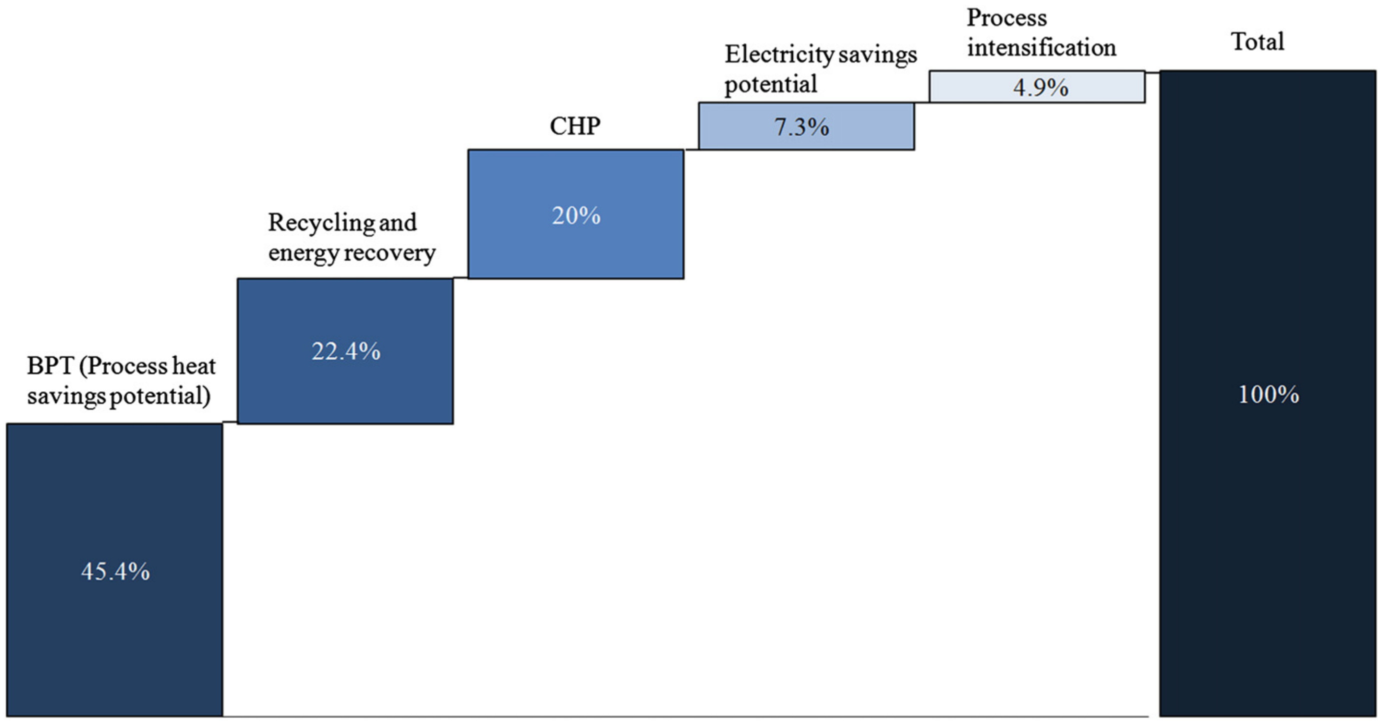

Fig. 1. The energy-saving share of each kind of BPT in the global petrochemical industry.
Sources: [6,25].

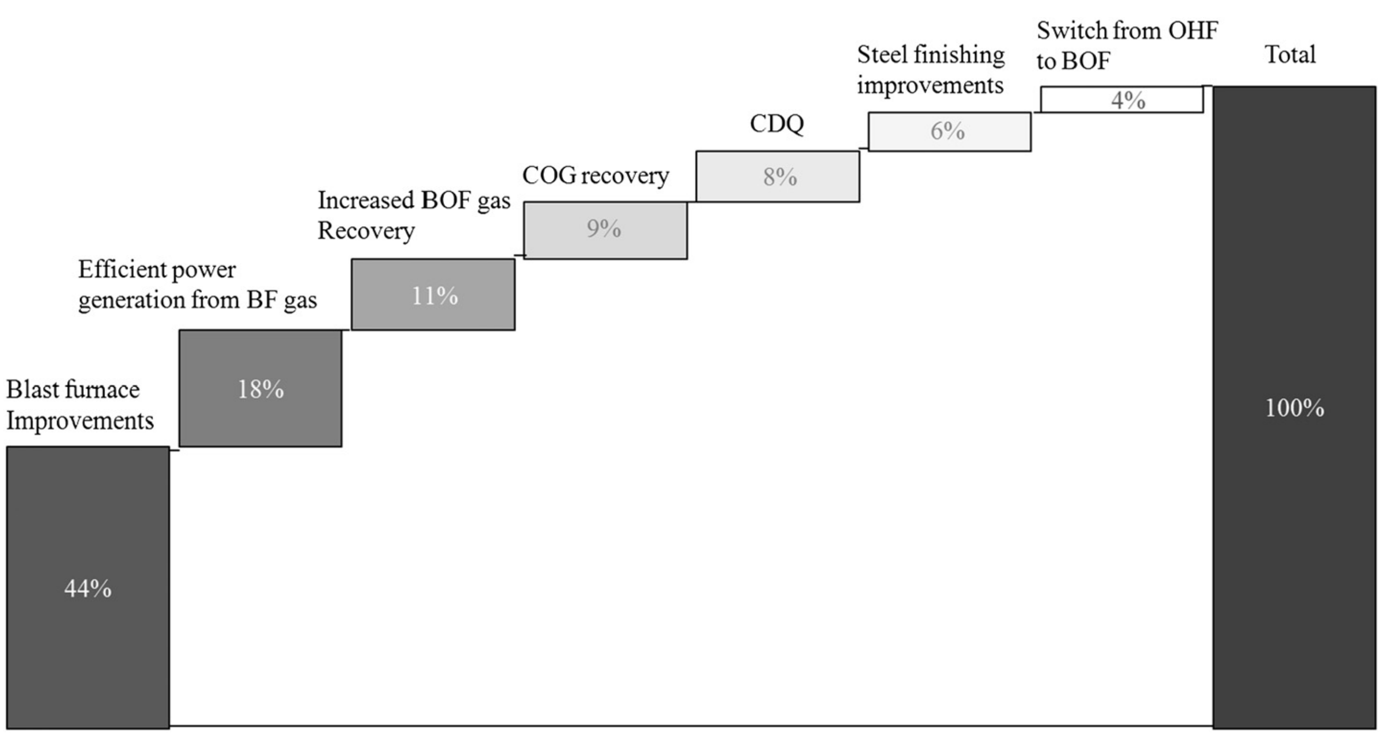

Fig. 2. Shares of energy-saving potentials of the global iron and steel industry under BAT scenario. *Note*: BF: blast furnace; OHF: open heart furnace; BOF: blast oxygen furnace; COG: coke oven gas; CDQ: coke dry quenching.
Sources: [6,27].

use is the majority, approximately two times the power consumption [28]. From the average survey of textile industry in Indonesia [29], the specific energy uses for textiles are 3.12–9.51 kWh/kg-polyester of electricity and 6.68–9.79 kWh/kg-polyester of heat.

As far as the textile manufacturing processes, the most power-consuming process is yarn manufacture, while the most heat-consuming processes are dyeing, printing and bleaching. Energy waste in general textile mills is very serious; 36% of the input

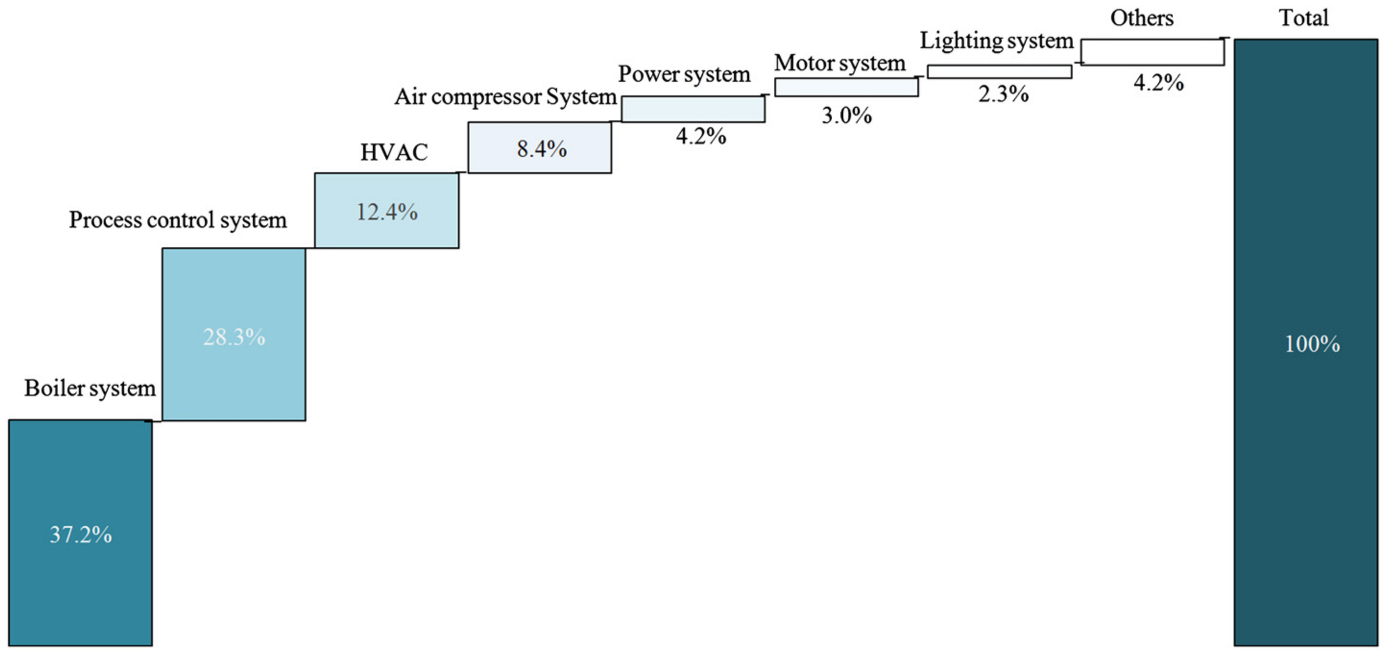

Fig. 3. Shares of energy-saving potentials of global textile industry if deployed with BAT.
Sources: [28,30].

energy is wasted, wherein the energy wasted by motors accounts for 13%, followed by transportation (8%) and boiler (7%) [28].

The shares of energy-saving potentials of global textile industry deployed with BAT are summarized in Fig. 3.

4.4. Profiles of cement production and its latest energy-saving technologies

The main ingredient of cement is calcium oxide. The cement making is generally comprised of several processes: mining, raw material grinding, preheating, clinker burning, cement grinding and packaging [31]. In the above processes, in addition to electricity (e.g., the grinding equipment and exhausting fan cover 80% power consumption [32]), the other main type of used energy is heat. Generally, the combining costs of electricity and heat are up to 50% of the cement's total sale costs [32].

Assessed by Lawrence National Laboratory, the United States [33], if introducing high efficiency measures to rolling machines and filters to produce cement particles of more uniform sizes, it may save energy of 21–27 kWh/ton-cement. For the most energy-intensive part – the heating process, if improving insulation systems, combustion process, flame shape, rotary kiln systems, cooling systems as well as heat recovery, the energy-saving potential can reach 520–900 kWh/ton-clinker. Similar to the grinding process for raw materials, if improving the efficiencies of rolling machines and particle filters in the clinker grinding process, there will be an energy-saving potential around 12–35 kWh/ton-cement. In terms of plant-wide system, by means of variable-speed drives, high efficiency motors, preventive maintenance and lighting efficiency improvement, they may also save energy around 5–20 kWh/ton-cement.

The shares of energy-saving potentials of global cement industry under BAT scenario are shown in Fig. 4.

4.5. Introduction to semiconductor manufacturing process and its latest energy-saving technologies

Integrated circuits (IC), different from most products, must be manufactured in a clean room environment. To meet the stringent requirements of a clean room, before flowing into which the air is required to pass through multi-layers of filters to significantly reduce the quantity of dust, mainly because any existence of dust will reduce the performance of components or burn down the circuits. In addition to the standards of size and number of dust particles, there are also strict standards for temperature, humidity and pressure regulated in the clean room. Therefore, air conditioning system significantly uses more energy than any other devices or facilities in a semiconductor manufacturing process. Due to lots of energy used in the maintenance of a clean room, its energy used per floor area is about 10–100 times the general office's.

Generally speaking, in the operation of a semiconductor clean room, electric energy accounts for 93% of the total energy used, 67% of which is used in the HVAC systems [34]. If further subdividing energy use items in the HVAC systems, then the fan uses 46% of electric energy, followed by process load (30%), cooling systems (18%), lighting (3%), pumps (2%) and cooling towers (2%). Therefore, in the HVAC systems of a clean room, the fan has the largest electricity-saving potential up to 50%, while that of the cooling system is about 30% and 10% for the cooling tower and pump respectively.

The shares of energy-saving potentials of global semiconductor industry implementing HVAC BAT are shown in Fig. 5.

4.6. Brief introduction to the papermaking process and its latest energy-saving technologies

Modern papermaking mainly takes plant fiber as raw materials (e.g., wood, bamboo, grasses, etc). The processes of major energy use in pulp making are steaming, boiling, modulating and bleaching. Each above steps use large amounts of steam.

In the papermaking processes, drying by far is the most energy-intensive, accounting for about two-thirds of the totally used energy. Black liquor, a byproduct of chemical pulping, can be recovered as boiler's fuel to produce heat and electricity. One ton of pulp can generate approximately 22 GJ of heat from the combustion of black liquor. Due to recovery and reuse of black liquor, a large pulp mill can generate electric power fed into grid, in addition to its self use [6]. By the comparison with virgin pulp, recycled pulp can save

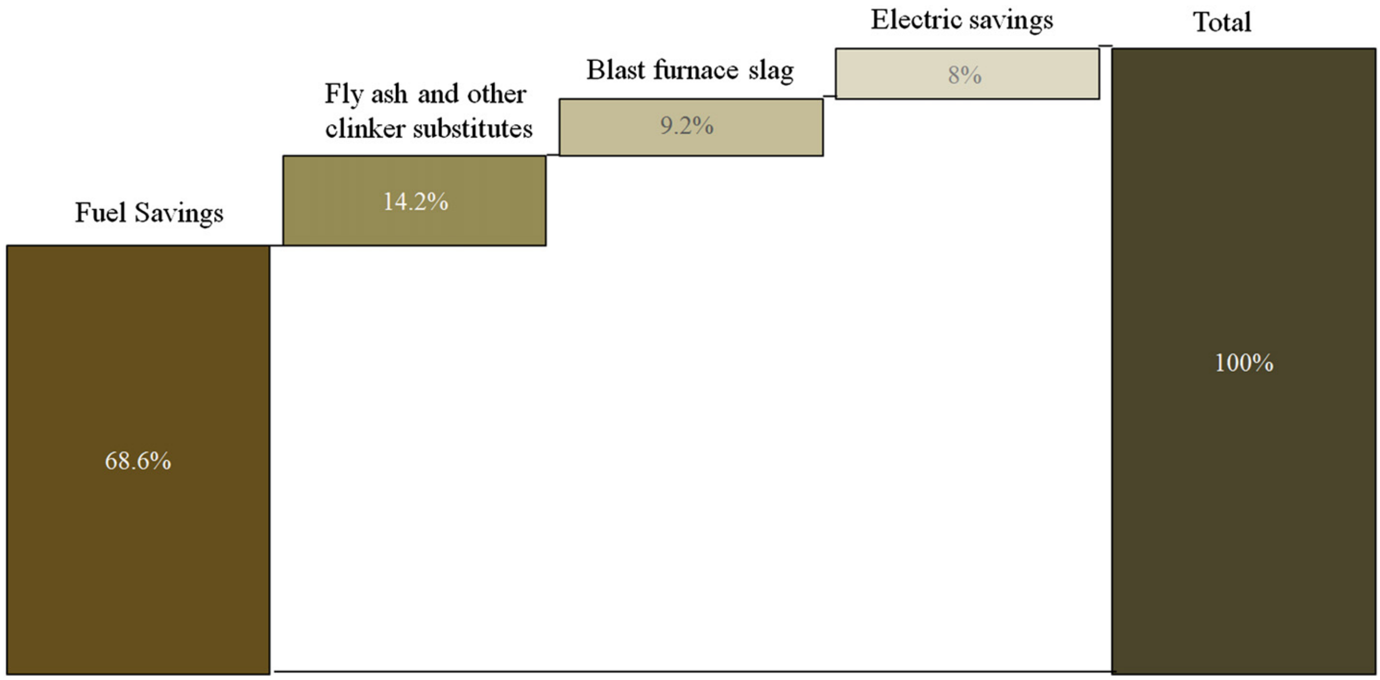

Fig. 4. Shares of energy-saving potentials of global cement industry under BAT scenario.
Sources: [6,33].

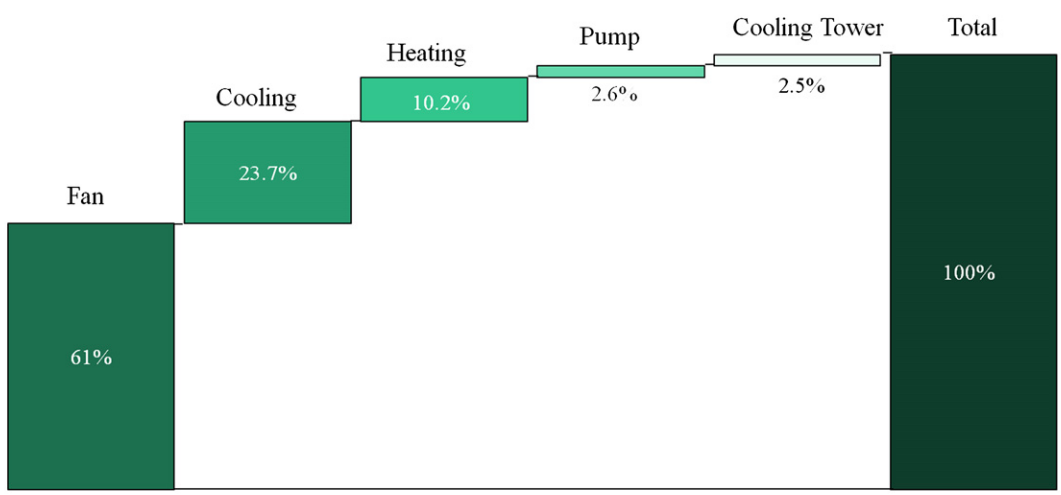

Fig. 5. Shares of energy-saving potentials of global semiconductor industry if implementing HVAC BAT.
Sources: [34].

energy about 10–13 GJ/ton-pulp [6]. An integrated plant containing both processes of paper and pulp makings is about 10–40% more energy efficient than the mill only having single process [6].

The shares of energy-saving potentials of global pulp and paper industry implementing BAT are shown in Fig. 6.

5. Maximal energy-saving potential evaluation for Taiwanese industrial sector under BAT scenario

The word-BAT (Best Available Technologies) comes from the European Union's IPPC (Integrated Pollution Prevention and Control) directive, meaning to prevent or reduce the overall environmental impact by means of the best advanced processes, equipments or operational methods. Factories will refer to BAT, when making planning or production improvement. BAT is also a main basis for the European Union to set the emissions standards that should be obeyed by the state nations. This study extended the definition of BAT as the current best practices of industrial scale technologies. Therefore, BAT is broadly defined as the best energy-saving and emissions-reducing technologies, which are economically viable. Another word-BPT (Best Practice Technology) comes from the IEA's world energy report 2006. The report studied how much the energy-saving potential would be, if applying the BPT to the chemical processes to improve a nation's energy efficiency.

The energy efficiency levels required by BPT and BAT are also different. Basically, BAT is the most efficient demonstrative technology so far, while BPT is the international energy use benchmark. In other words, if the index value of BPT were 1, then the index value of BAT would be about 0.6, meaning that the energy efficiency of BAT is 40% higher than that of BPT. The percentage of BAT now used in the industrial sector of the world is about 5%, while that for BAT is about 10%. In addition, in the

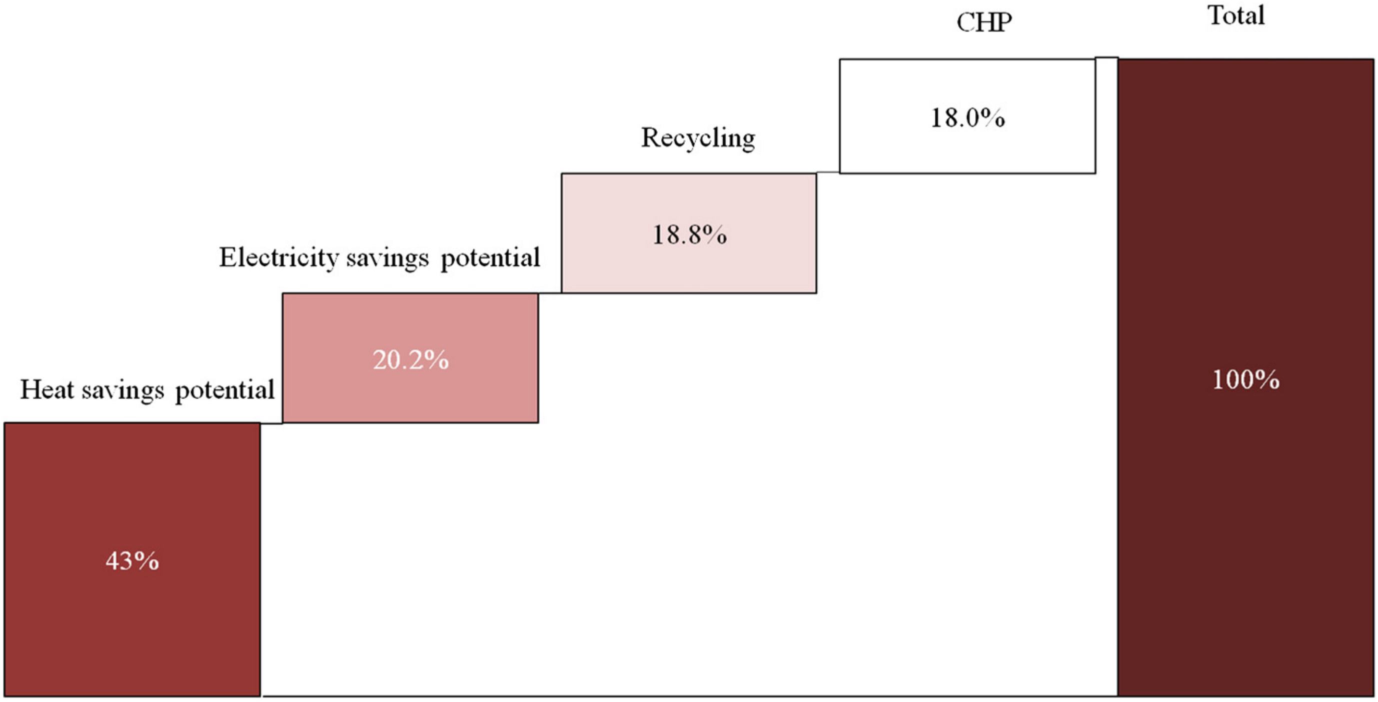

Fig. 6. Shares of energy-saving potentials of global pulp and paper industry if implementing BAT.
Sources: [35].

Table 3
Potential analyses of energy saving and emissions abatement of the six largest industries in Taiwan (Base year: 2010).

Item	Industry	Energy use				Energy saving				Emissions reduction* [36,37]		
		TWh	Sector share (%)	Electricity (TWh)	Heat (TWh)	Energy-saving potential (%)	Electricity (TWh)	Heat (TWh)	Sub-total (TWh)	Electricity Mt-CO_{2e}	Heat Mt-CO_{2e}	Sub-total Mt-CO_{2e}
1	Petrochemical	321.8	47.5	68.2	253.6	13.2	3.1	39.4	42.5	0.76	9.64	10.40
2	Iron and steel	63.1	9.3	38.4	24.7	12.2	2.5	5.2	7.7	0.60	1.28	1.89
3	Textiles	23.1	3.4	16.1	7.0	20.0	2.9	1.7	4.6	0.71	0.42	1.13
4	Cement	19.1	2.8	5.0	14.1	21.3	0.5	3.6	4.1	0.12	0.88	1.00
5	Paper and pulp	17.2	2.5	10.8	6.4	16.4	0.6	2.2	2.8	0.14	0.55	0.69
6	Semiconductor	16.9	2.5	16.6	0.4	27.0	7.1	−2.5	4.6	1.74	−0.62	1.12
	Total	461.3	68.0	155.1	306.2	14.4	16.6	49.7	66.3	4.07	12.16	16.22

* Emissions reduction (Mt-CO_{2e}) = Energy saving (TWh) × Thermoelectric conversion efficiency (0.4) × Electricity emissions factor (0.612 kg CO_{2e}/kWh).

section of last 10% of the global industries, its energy use index is about 1.4, which means that its energy use efficiency is 40% lower than that of BPT benchmark [8].

Please refer to Table 3. The main purpose of this article is to assess the energy-saving potential in the industrial sector of Taiwan. In addition to the four most energy-intensive industries referred by the IEA [6]–chemical materials, iron and steel, cement, and paper and pulp, this study further included textiles and semiconductor industries. In 2010, the total industrial energy use of Taiwan was about 677.1 TWh [4], in which the total energy use of the six major industries was about 461.3 TWh, the share of which in the industrial sector was approximately 68.1%. In this study, we used BPT scenario to assess the energy-saving potential of the petrochemical industry, while BAT scenarios were applied to the other five industries. The results showed that the total energy savings of the above mentioned six industries are about 66.3 TWh, namely, with a combining potential up to 14.4%. Although the petrochemical industry only has an energy-saving potential of 13.2%, due to its energy use share being as high as 51.7% in the industrial sector (Table 1), its energy savings are up to 42.5 TWh. Therefore, the energy saving of petrochemical industry accounts for 64.1% by taking the six major industries as a whole. Essentially, the petrochemical is the most crucial industry to reduce the energy use in the industrial sector. The energy savings for other industries are 7.7 TWh for the iron and steel, 4.6 TWh for the textiles, 4.6 TWh for the semiconductor, 4.1 TWh for the cement and 2.8 TWh for the paper and pulp.

The common BAT used in the industrial sector includes cogeneration (i.e., combined heat and power, CHP), efficient motor and steam systems, waste heat recovery and utilization of waste [6]. In respect of fuel and raw material substitution, the extensive use of biomass energy is an important measure. If intending to truly achieve the emissions-reducing targets in the full scale, the carbon capture and storage (CCS) will be the most critical technology in the future [6].

Table 3 indicates the maximal energy saving potentials for the six major industries in Taiwan, if introducing BAT or BPT. In terms of individual industries, the semiconductor with a rather high percentage of electric energy use has the highest energy saving potential of 27.0%, followed by the cement (21.3%), the textiles (20.0%), the paper and pulp (16.4%), the petrochemical (13.2%), and the iron and steel (12.2%).

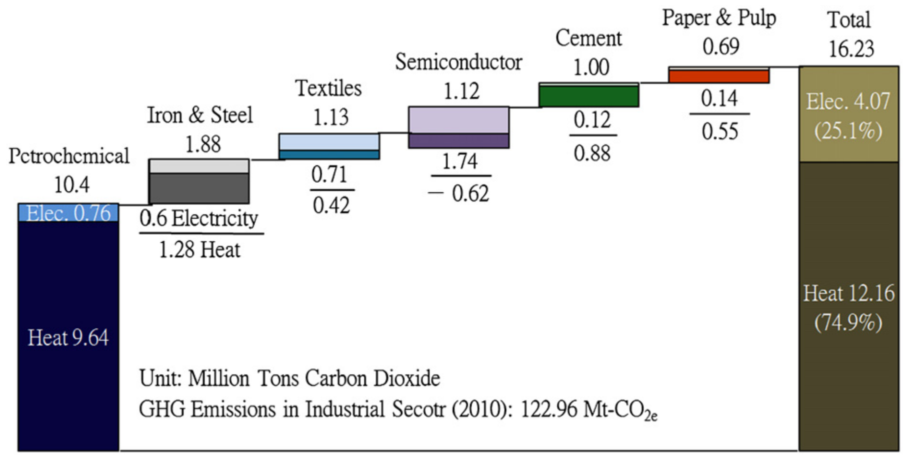

Fig. 7. Emissions abatement potentials of the six largest industries in Taiwan (Base year: 2010).

According to the IEA's estimation [6], the average energy saving potential of global industrial sector under BAT scenario is about 18%, while that for Taiwan is about 14.4% according to this study. The industry with higher energy-saving potential means that its existing process is less energy efficient or its equipment is out of date, needing a large scale of improvements and updates. By contrast, the industry with lower energy-saving potential means that its processing technique is more advanced. Due to either of both, the resulted high competitiveness will naturally increase the earnings of corporation. In Taiwan, the successful examples are China Steel Corporation and Formosa Plastics Corporation. Both companies represent the profit-leading enterprises respectively for iron and steel industry and petrochemical industry in Taiwan. In addition, the energy intensity of Taiwanese semiconductor products is as low as 1.18 loe/thousand NT$ (Table 2), which is the reason why the Taiwanese semiconductor industry can stably earn high profits. However, based on the analysis of Table 3, because the energy-saving potential of semiconductor industry is as high as 27%, there is still a lot of room to be improved for the energy saving in the semiconductor industry. At the same time, the petrochemical industry has the largest energy savings, 42.5 TWh, accounting for 64.1% of the total energy saving of the six largest industries and for 6.3% of the entire industrial energy use. Therefore, it can be seen how significant the influence of the energy-saving of the petrochemical industry will be on the entire industrial sector. Worthy of note is that the cement industry has the largest energy intensity, 50.51 loe/thousand NT$ (Table 2), so the cement industry has the second largest energy-saving potential—21.3% (Table 3). Obviously, the cement industry is a high energy-intensive and high pollution industry. Taking 2010 as base year, the maximal energy-saving potential for the six largest industries in Taiwan is 14.4%, equivalent to 5.3% of the national energy use per year. As shown in Fig. 7, by means of emissions coefficients and thermoelectric conversion efficiency (0.4), we can get the maximal GHG emissions-reducing volumes for the six largest industries in Taiwan. Overall, there is positive relationship between the energy use and GHG emissions in terms of Taiwanese industry.

6. Conclusion and discussion

This research adopted the data of National Lawrence Lab. in the USA, the BAT and BPT by the IEA and the statistics of MOEABOE, by taking 2010 as base year, to assess the energy-saving potential in the Taiwanese industrial sector. Results showed that the energy saving potential for the entire sector is 14.4%, while the sectoral energy saving (66.3 TWh) accounts for 5.3% of the national energy use per year [1] wherein the heat-saving potential is about 49.7 TWh or 16.2%, and the electricity-saving potential is about 16.6 TWh or 10.7%. Generally speaking, the heat used in the industrial sector of Taiwan is about 2 times the electric energy. Correspondingly, the maximal GHG emissions-reducing potential of Taiwanese industrial sector reaches 16.2 Mt-CO_{2e}, accounting for 6.4% of the national GHG emissions per year. The IEA analysis showed that if today's best available technologies (BAT) were deployed globally, the industrial energy use can be reduced by 20–30% [6], while that of Taiwan will be reduced by 12–27% estimated by this paper.

The energy-saving potential in Taiwanese industrial sector estimated by this article is about 14.4%, which is less than 30% of the United Kingdom [9], 25% of India [12], 27–30% of the United States [19], 15–30% of Indonesia [13], 31–54% of China [20], and 20% of Spain [22]. One reason of the lower energy saving potential for Taiwanese industrial sector may be explained by the energy assessment method used by the most energy-intensive industry-petrochemical industry that was assessed by BPT rather than BAT. After all, there is still a considerable gap between these two benchmarks. For example, in the IEA reports, the existing petrochemical technology of both India and China has surpassed the BPT already (i.e., it is supposed that there were no room for improvement). However, the energy development agencies of Maharashtra estimated that there is still 10–15% room for the improvement of petrochemical industry in India [11]. Meanwhile, according to the assessment by Lawrence laboratory, there are still 31% and 53% of energy-saving potentials for the ethylene and ammonia manufacture in China [20].

For the assessment of other industries, this study adopted the BAT scenarios. In other words, their energy-saving potentials were calculated according to the differences between the Taiwan's current energy use and the BAT benchmarks. Thereby, the energy-saving potential of the cement industry in Taiwan is 21.3%, which is close to the result of the global cement industry by UNIDO, but higher than India's (10–15%) and less than China's (38%) [8,11,20]. Energy-saving potential of the steel industry in Taiwan is 12.2%, which is close to those of India (8–10%) and France (10% of electricity and 20% for heat), and which is also close to the values estimated by the UNIDO for the ICs countries—10% [8,11]. Meanwhile, the energy-saving potential of Taiwanese textiles and paper industries are respectively 20.0% and 16.4%, which

are generally between the results estimated by the UNIDO on ICs (i.e., respectively 10% and 25%) and non-ICs (i.e., 20% for both) [8,21].

Generally speaking, there are two kinds of approaches used to assess the energy-saving potentials of the industrial sector in a county's scale; namely, the ''Top-down'' and ''Bottom-up'' methodologies. The ''Top-down'' approach adopted by the present study is a marco-perspective and long-term estimation, such that our outcomes are close to those of the IEA and UNIDO [8,14,15,17], but significantly greater than those of ''Bottom-up'' methodology or the so-called ''in-situ energy audit'' approach adopted by Islam [16], Chan [18] and Aranda-Usón [22].

In fact, if excluding the petrochemical industry, the assessment gaps between Taiwan and the rest of other countries will be significantly narrowed. In the future, by combining the scholars with the industries, the energy-saving technologies or measures of Taiwanese petrochemical industry should be further improved to reflect a greater potential of its energy saving.

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